Computer-Assisted Analysis of Near-Bottom Photos for Benthic Habitat Studies

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***Abstract*- This paper reports on a methodology developed for the analysis of near-bottom photographs collected for fisheries habitat studies. These tools provide a framework for conducting minimally invasive in-situ investigations of benthic organism abundance, diversity, and distribution using high-resolution optical datasets integrated with high precision navigational data. Utilizing these techniques with near-bottom photos collected with a precision navigated survey platform greatly increases the efficiency of image analysis and provides new insight about the relationships between benthic organisms and the habitats in which they are found.**

Basic requirements for the analysis of near-bottom seafloor images include camera calibration and quantification of the height of the lens above the seafloor throughout the survey. Corrections are required to compensate for image distortion due to lighting limitations and the variable micro-topography of the seafloor. These parameters can be constrained by utilizing precisely navigated survey platforms such as Autonomous Underwater Vehicles (AUVs) or Remote Operated Vehicles (ROVs).

The methodology we present was developed with data collected by the SeaBED AUV off the coast of Washington, Oregon and California [1]. A digital database containing benthic organism identifications, measurements, and locations was generated for each image using a Graphical User Interface (GUI) created in Matlab™ [1,2]. This methodology has demonstrated a significant increase in the efficiency of image analysis for benthic habitat studies, and provides the opportunity to assess small scale spatial distribution of organisms in their natural habitats. Collecting overlapping images permits the creation of photomosaics [3] and the quantification of organism abundance per unit area of the seafloor.

I. INTRODUCTION

Fish population assessments have traditionally been based upon observations of organisms captured in fishing trawls Although observations are not made in-situ, correlations can be made between fish populations and observations of seabed characteristics derived from co-located sonar surveys and/or bottom photographs collected in discrete locations. Fish populations that dwell in rocky environments, however, are difficult to assess with trawl surveys because of the risk of fowling gear on the seafloor. Surveys have also been conducted with video cameras placed on towed vehicles but these platforms are also not ideal for rugged, rocky habitats.

Autonomous Underwater Vehicles (AUVs) with precise navigation provide new alternatives to fish population and habitat assessment. Near-bottom high-resolution digital photographic surveys conducted with AUVs are minimally invasive, and provide a means for in-situ observations of organisms. When performed at slow survey speeds, a continuum of photographic information can be acquired along the survey track. These images not only provide quantitative data about benthic habitat, but can also be used to identify fish in their natural habitat. Surveys of this nature also provide a means for ground-truthing geoacoustic facies identified with high-resolution geophysical mapping techniques.

Since hundreds of digital images are typically collected during each AUV dive, analysis can be very time consuming. Software tools that allow scientists to digitally identify and annotate organisms imaged in photos are required to efficiently utilize these vast datasets. When in-situ observations of organisms are combined with precision navigational data, new insights can be gained about the spatial distribution of organisms and the habitats in which they live.

II. DATA ACQUISITION

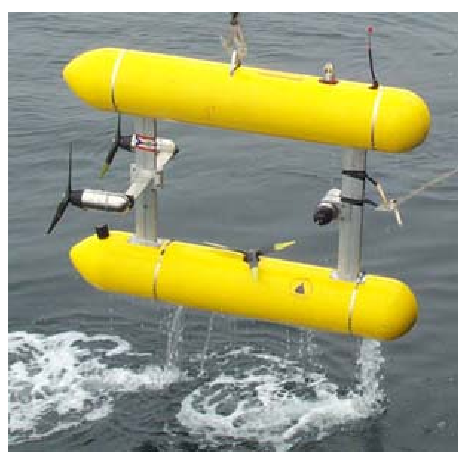

Figure 1. The SeaBED Autonomous Underwater Vehicle (AUV) is designed for benthic studies in rugged terrain. It can be used to conduct low-altitude (2.5 m) surveys yielding high-resolution digital images.

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The SeaBED AUV (Fig. 1) is navigated through the use of a Doppler Velocity Log (DVL) navigation system, resulting in meter-scale navigational precision [4,5]. It is equipped with a high-dynamic range down-looking camera that collects high-resolution (0.15 cm/pixel) color imagery.

The nonlinear attenuation of visible light in seawater means that images typically wind up looking far more green or blue as we move away from the object being images. That is, the reds in the imagery are preferentially attenuated as a function of distance. If we use standard (8 bit) dynamic range cameras the level of signal in the red channel in the imagery is very small, comparable to the noise levels of the camera. However, by utilizing high dynamic range 12 bit imagery, even though the signal level of the red channel is small, it is enough that we can rescale it to compensate for the nonlinear attenuation.

The rescaling process for the different color channels is carried out by fitting a polynomial surface to each of RGB channels of the image to bring them into rough parity in terms of signal strength. By utilizing a single ground truth point in color space the resulting equalized RGB imagery may be transformed to obtain colors that are representative of what we would see if we could image the scene without water in sunlight. Figure 2 shows an example of SeaBED imagery before and after color correction.

Figure 2. Typical 12 bit dynamic range imagery collected by the SeaBED AUV (top) and the results after color correction (bottom).

All our imagery is color corrected in this fashion. The imagery is also post-processed to compensate for lens distortion.

Over 30,000 near-bottom digital images were acquired with SeaBED during a 2 week cruise in October 2006 aboard the R/V Thomas G. Thompson. AUV surveys complemented seafloor mapping conducted at three fishing areas along the west coast of the U.S. from Washington to California. AUV surveys were conducted at an altitude of 2.5 m yielding an average image area of 3 m^2.

Although we focus in this paper on the imagery collected during this expedition, the tools reported here are equally applicable to imagery collected from other imaging platforms.

A Graphical User Interface (GUI) was developed in Matlab™ for identification and digital annotation of organisms visible in the images. The GUI is used to record a list of organisms, information about their size and habitat type, and the geospatial information associated with each image.

III. Graphical User Interface

The interface that was developed merges digital photographs with the vehicle's precision navigation. It is used to browse images and to identify and annotate organisms and objects evident in them (Fig. 3). Navigational data are used to reference the images geographically, and altitude data are used to estimate the image footprint assuming a flat seafloor.

Organism taxa are chosen from predetermined lists, and each individual is identified and counted with a click of the mouse button. For each organism that is identified a cross-hair symbol is plotted based on a user defined position in the image. Organisms not included in the lists can be counted and identified via manual entry of taxa information. Length and area tools are provided to assign measurements to organisms and/or seafloor objects, based on the assumption that objects are on the seafloor. Benthic habitats are described for each image based on a binary classification system for describing sediment type (Fig. 4).

Data tabulated for each image include navigation, attitude, estimated image area, organism identifications, positions within the image, and substrate type are logged in a comma delimited text file. When the GUI is reopened and images previously analyzed are viewed, previously defined annotations are displayed on the image. This provides a means for quality control and for adding additional annotations. Upon closing the interface, all text files contained within the working directory are assembled into a self-updating master list. An option is also provided to save annotated tiff images.

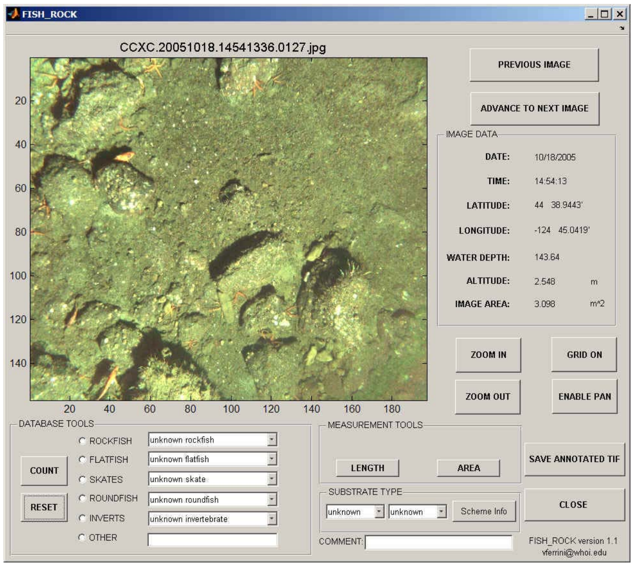

Figure 3. FISH_ROCK interface for computer-assisted identification of benthic organisms.

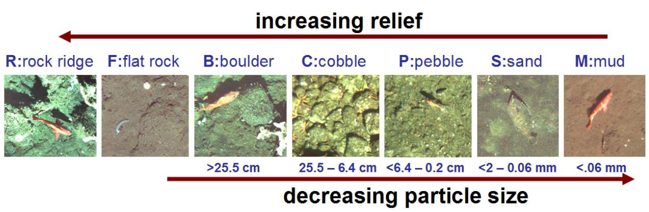

Figure 4. Binary habitat classification scheme (after [6]). The first letter in the binary scheme represents the dominant substrate (> 50% image area), while the second letter represents the secondary substrate (> 20% image area).

IV. Application of Interface

Three different sample designs were tested to determine the optimal number of transects and images required for statistically significant results. Two of these sample designs utilize alternate images along a transect, while the third design uses random images. The random image approach requires that an order of magnitude fewer images be analyzed than the other approaches.

Observations of benthic organisms were used to investigate relationships between benthic habitat and two dominant categories of fishes: Rockfish and Flatfish. Roughly half of all organisms identified in each category were identified to species (46% and 65% respectively). As expected, the majority of rockfish were identified in habitats dominated by rocks, boulders and cobble (Fig. 5). Similarly, the majority of flatfish were identified in boulder-dominated habitats (Fig. 6).

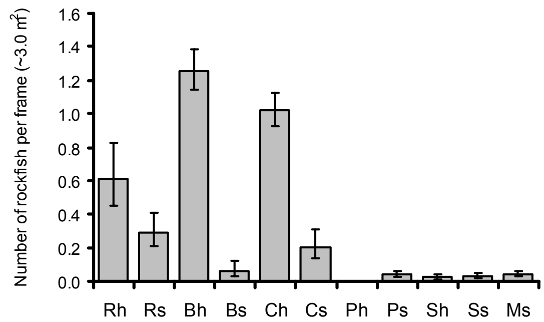

Figure 5. Average number of rockfish per image based on substrate type.

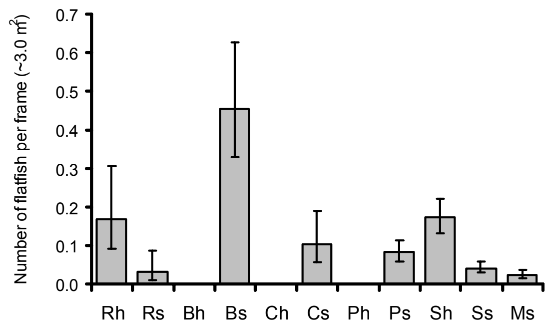

Figure 6. Average number of flatfish per image based on substrate type.

Data generated with the GUI were also imported directly into Geographic Information System (GIS) software to investigate the spatial distribution of benthic organisms (Fig. 7). This reveals relationships between benthic organisms and seafloor characteristics derived from geophysical mapping techniques. In addition, each observation plotted in Fig. 6 can be directly linked to the original image of the seafloor.

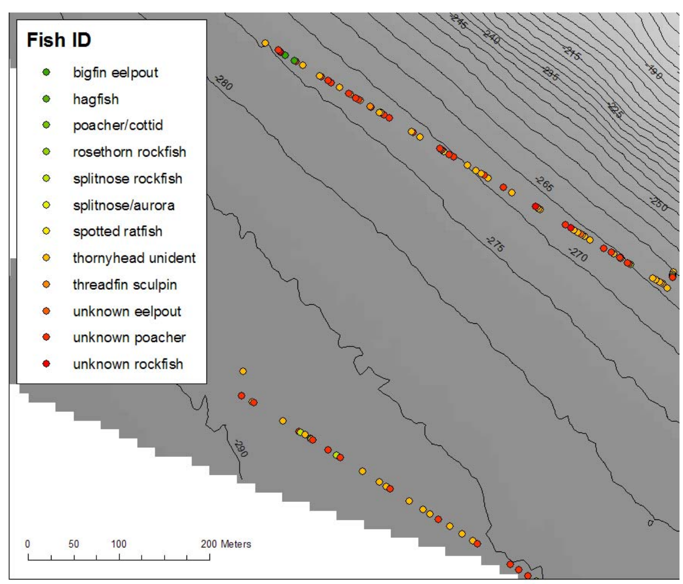

Figure 7. Identified fish overlain on bathymetry data in GIS.

V. Conclusions and Plans for Future Development

Precision navigated vehicles equipped with high-resolution digital cameras are becoming increasingly common tools used for a variety of oceanographic investigations. The computer-assisted approach to analyzing digital photos described here provides a framework for quantitatively using these datasets for in situ studies of benthic organisms in their natural habitats. Although developed for an AUV, this approach can also be used with precisely navigated towed camera systems.

Further development of this software will utilize feature matching functionality used in photo-mosaicing software [3] to automatically remove observations of organisms identified in consecutive images (Fig. 8). This will result in a continuum of observations along the entire AUV survey track, and will permit the calculation of organisms per unit area. This functionality has already been developed, and it will soon be implemented. More complex algorithms will also be included to perform supervised classification of organisms. In addition, consecutive images with overlap can be used for 3D image reconstruction**.** This could be used to quantify seafloor microtopography, and to measure objects and organisms that are not on the seafloor.

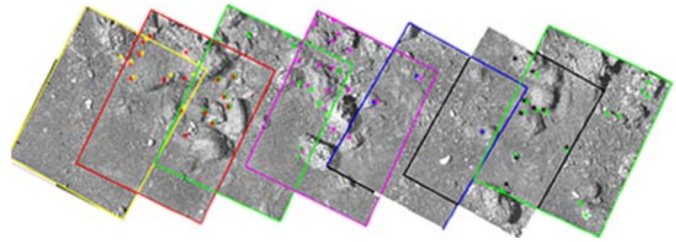

Figure 8. Photo-mosaicing algorithm combined with observations of organisms. This technique can be used to remove redundant data from consecutive images.

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